



## Deploying scanning lidars at coastal sites

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# Deploying scanning lidars at coastal sites

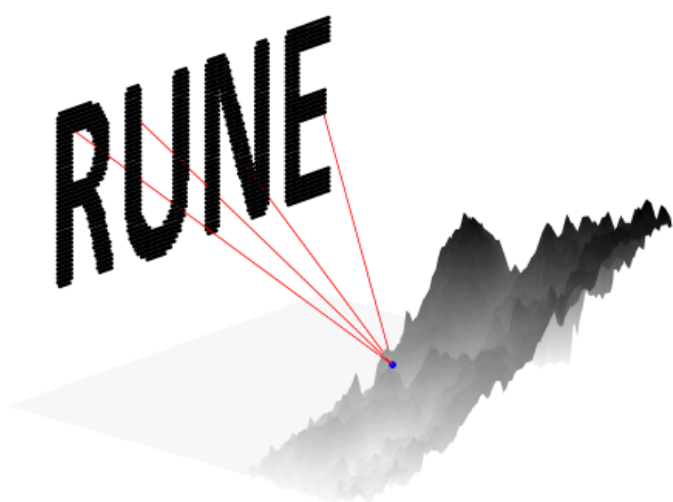
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RUNE



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**Title:** Deploying scanning lidars at coastal sites

**Department:** DTU Wind Energy, Risø Campus

**Summary (max 2000 characters):**

This report presents the concept of scanning lidars placed at coastal sites in order to measure the near-coastal (offshore) wind resource. In particular, the site requirements for such scanning lidars are examined in the context of the siting choices made for the RUNE project. It is seen that the most desirable sites are away from sand dunes and with some significant elevation above the sea surface, such as at the top of a cliff. Coastal planning restrictions in Denmark are quite restrictive and it was important to allow sufficient time to obtain permission from the relevant authorities. At the same time, with our particular application, the authorities and land owners were quite favourably inclined to give permission to temporary installations in support of wind energy research. The report concludes with the final positions and a pictorial description of the three RUNE scanning lidars.

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# Preface

This report encompasses deliverable D1.1 of the ForskEL project RUNE (Reducing uncertainty of near-shore wind resource estimates using onshore lidars).

DTU, Risø Campus, April 2016

Michael S. Courtney & Elliot I. Simon

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## Summary

This report presents the concept of scanning lidars placed at coastal sites in order to measure the near-coastal (offshore) wind resource. In particular, the site requirements for such scanning lidars are examined in the context of the siting choices made for the RUNE project. It is seen that the most desirable sites are away from sand dunes and with some significant elevation above the sea surface, such as at the top of a cliff. Coastal planning restrictions in Denmark are quite restrictive and it was important to allow sufficient time to obtain permission from the relevant authorities. At the same time, with our particular application, the authorities and land owners were quite favourably inclined to give permission to temporary installations in support of wind energy research. The report concludes with the final positions and a pictorial description of the three RUNE scanning lidars.

# 1. Introduction

## 1.1 The need for coastal scanning lidars

Along with better wind resources, the political unpopularity of land-based wind farms witnessed in most of northern Europe is driving the search for more and more offshore wind farm locations. Since many of the ideal sites (with shallow water, good wind climate, and lack of dominating, conflicting interests) have already been developed, the search continues to less perfect locations. These can be either closer to shore (poorer resource but cheaper costs) or further offshore (better resource but higher development costs). It is this first group that we are primarily interested in with this report – the so-called ‘near coastal’ wind farms that, loosely defined, are placed between 3 and 12 km off the coast.

A second trend, relevant to this report which we are currently witnessing, is the technical and commercial acceptance of scanning lidars. By ‘scanning lidars’ we mean wind speed measuring lidars that have a scanning head allowing the trajectory to be (within the half-dome limits) arbitrarily chosen as opposed to being completely fixed by the construction (see example [1]). We are concerned in this report with using coastally (ground based) scanning lidars to measure the near coastal (offshore) wind resource. Examples of relevant scanning lidars include the Lockheed Martin Windtracer, the Leosphere Windcube W400S and a long range scanning lidar from Mitsubishi Electric.

The common link between the emergence of scanning lidars and the increasing interest in near-coastal wind farms is the possibility of placing such lidars at relevant coastal sites with the task of providing wind resource data in the potential near-coastal wind farm areas. Such data would be used to improve the accuracy of resource estimates from mesoscale modelling (e.g. WRF) without having to incur the high cost of deploying fixed offshore measuring masts. The feasibility of this concept is being studied in the RUNE project.

All wind lidars share the limitation that they are only able to measure the wind speed projected along the line in which they are pointing their laser beam (the so-called ‘radial speed’ along the ‘line of sight’). In order to obtain the horizontal wind speed and direction, it is necessary either to measure in more than one direction and assume that the lidar is measuring different projections of the same wind speed or to measure with more than one laser beam originating from different positions. In both cases the radial speeds obtained from the different projection angles can be used to derive the wind speed vector.

Long range scanning lidars can thus be used in two primary ways for measuring the horizontal wind field offshore. One scanning lidar can be used in so-called ‘sector scanning’ mode, in which the lidar scans along a partial PPI (plan position indicator) arc of typically  $>30^\circ$  and derives the wind speed and direction from the spatial variation of the radial speed fit to a cosine function. Alternatively, two spatially separated lidars can be used in tandem to measure the wind speed at the intersection of the beams. This is known as ‘dual Doppler’ mode. Triple Doppler configurations will not be discussed within the context of this report.

In the first case, only one lidar must be positioned on the coast. In the second, two lidars must be positioned with an appropriate angular separation to resolve the distance of interest. The purpose of this report is to explore the requirements and limitations in performing this siting both for the single and dual lidar cases. We will first examine the generic requirements for coastally sited scanning lidars and then examine the more specific requirements of the RUNE project. The report concludes with details of the specific sites identified and utilised within RUNE deployments.

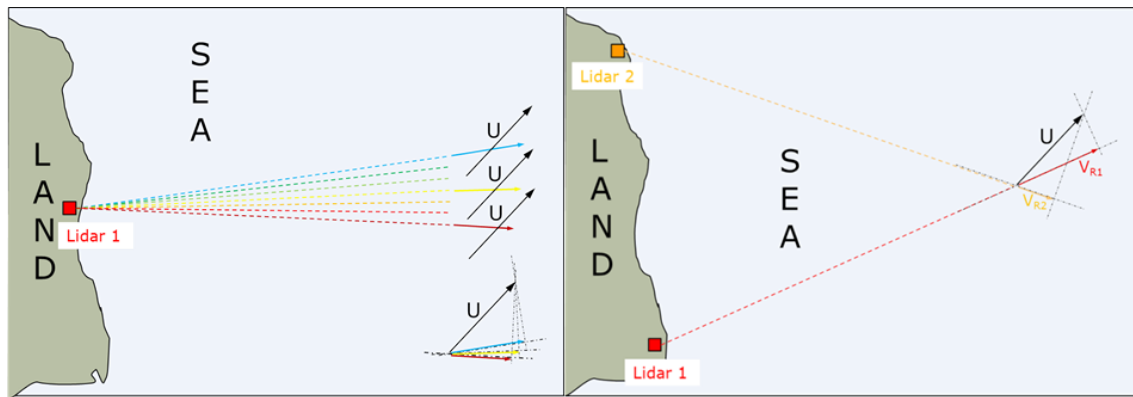


Figure 1 Coastal scanning lidars. Left panel - sector scanning configuration, Right panel – dual Doppler configuration

## 2. Site requirements for coastal scanning lidars

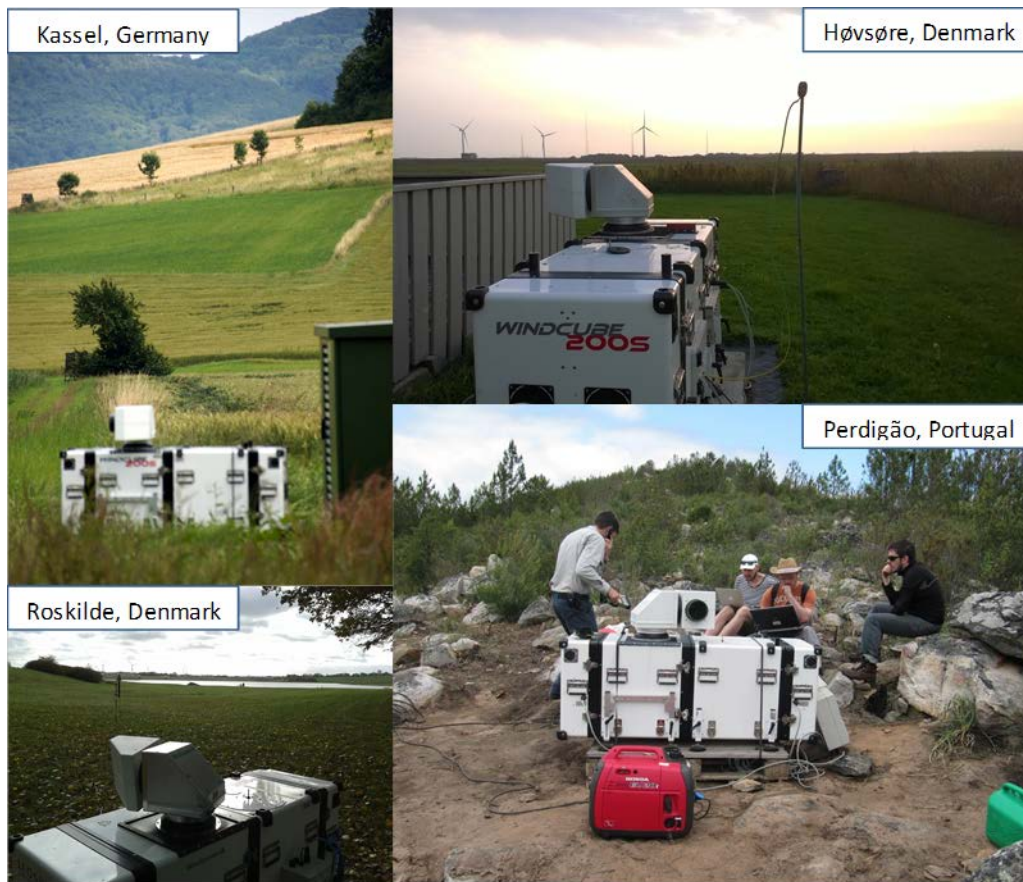
### 2.1 Characteristics of a typical scanning lidar

Here we will briefly present an introduction to the typical physical characteristics of a scanning lidar. For this purpose we have chosen the Leosphere model W200S, which comprises the hardware component of the Windscanner systems used in the RUNE campaign. Table 1 provides the basic specifications for this lidar and Figure 2 shows the same lidar deployed in various terrain types.

Table 1 Mechanical and electrical specifications of a Leosphere W200S scanning lidar.

<b>Laser</b>	
Wavelength	1,54 $\mu\text{m}$
Eye safety	IEC/EN 60825-1 compliant / ANSI-Z136.1-2007 compliant
<b>Environment</b>	
Operating temperature	-15°C to + 40°C
Humidity	IP65 (streaming)
Dust protection	Window cleaning sweeper & pump
Transportation	Portable (4 people)
<b>Dimensions</b>	
Weight	170 Kg
Dimensions	L1570 x l680 x h640 mm for body and h=1000 mm with the scanner head
<b>Electrical specification</b>	
Power supply	[100-240] VAC ; [50-60] Hz – Converted into 27 VDC - Instrument
Power consumption	500 to 2000 Watts





**Figure 2** The Leosphere W200S lidar deployed in various locations and terrain types.

## 2.2 Generic site requirements

Here we will specify the necessary generic conditions for deploying a coastally scanning lidar:

- A clear view of the scanning area without obstruction
- A stable and compacted surface to place the lidar on that will not be eroded by water, wind or ice
- Availability of a reliable electrical power supply (typically 1-2 kW @ 230VAC)
- Availability of a reliable communication system (e.g. 4G modem with good signal)
- A realistic chance that the system will not be damaged accidentally or on purpose
- A very low chance that the system can cause injuries to people, animals or the environment
- A low chance that the system can cause annoyance (e.g. noise or reflections) to people
- A high chance that the location will be approved by the relevant authorities
- Reasonably easy vehicular access for installation, servicing and removal

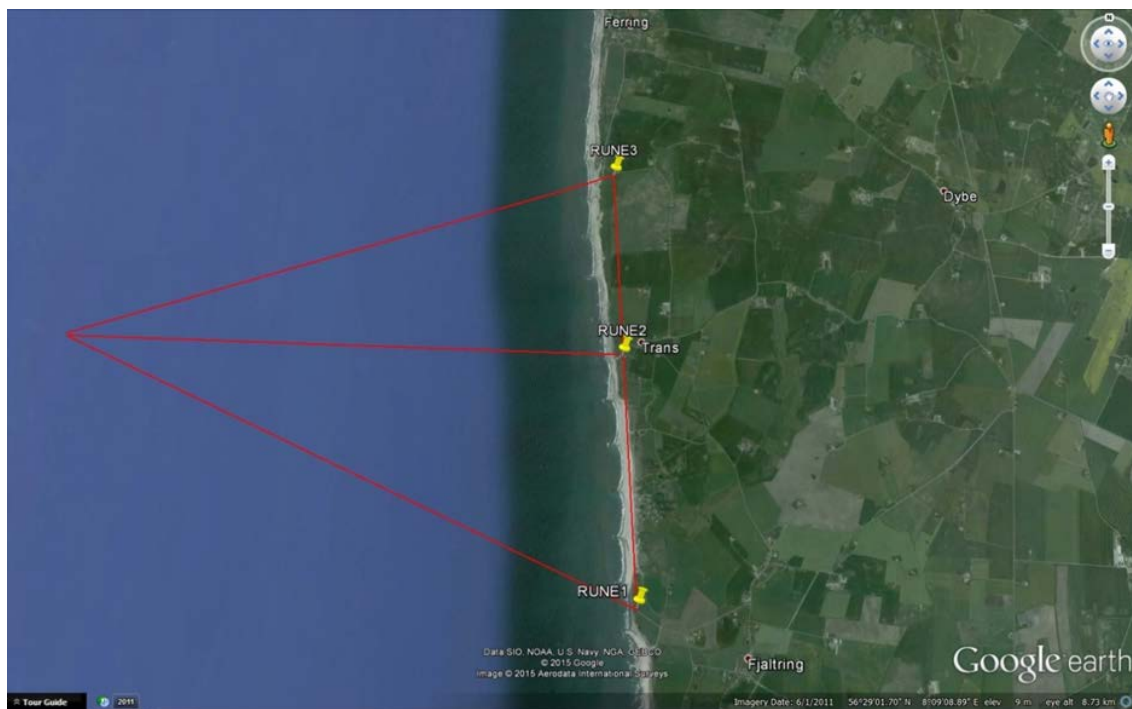
## 2.3 Differences for sector scanning and dual-Doppler setups

From Figure 1, it is clear that the choice between sector scanning (one lidar) and dual-Doppler (two lidars) will affect both the number and location of the coastal sites relative to the offshore area to be prospected. In Figure 1 we have depicted a scenario with the shortest possible distance to the shore. While this is normally preferable (to maximise the lidar signal strength and availability), the direction of the prevailing wind also needs to be taken into consideration. Especially for the sector-scanning configuration, wind directions approaching perpendicular to the centre of the arc will increase measurement error and lead to larger uncertainties in the resource estimate. For the dual-Doppler case, the two coastal sites should give an angle between the crossing beams at 5km offshore of minimum 30 degrees, in order for the wind speed and direction to be well resolved [2][3].

## 2.4 Site choices specific to the RUNE project

For the RUNE campaign, we did not have a particular offshore wind farm site in consideration. Rather it was important to find coastal sites that could be easily serviced from our existing test stations in the west of Denmark (Høvsøre and Østerild).

Another peculiarity of the RUNE campaign is that we have deployed lidars performing both sector scanning and dual Doppler measurements. This is to give us the best possible comparison between the two methods in determining their suitability for near-shore resource assessments. Our choice is thus a hybrid of the two geometries shown in Figure 1 where the sector scanning system is positioned approximately half-way between the two dual-Doppler lidars as shown in **Figure 3**.



**Figure 3 Final geometry of the three lidars used in the RUNE campaign.**

The distance between RUNE1 and RUNE3 is 3.87 km.

## 3. Case study – sites investigated for RUNE

A search for suitable sites for the RUNE campaign was made between the towns of Thorsminde and Thyboron on the western coast of Jutland. This stretch of coastline was selected because it has quick and easy access from DTU's Høvsøre test station and represents a typical location of interest for offshore wind development (ex. Horns Rev I & II). Additionally, the area is well documented from past experiments and is familiar to DTU scientists and engineers. The entire area is well serviced by the Telenor 4G data network for device monitoring, control and data retrieval.

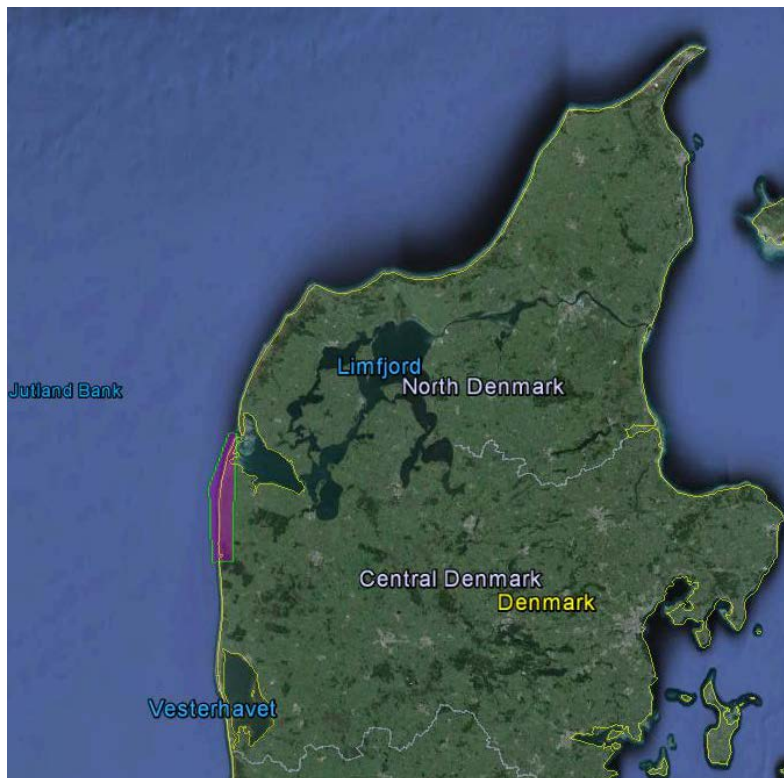


Figure 4 Location of the considered area within Denmark (shaded in purple)

The linear distance from Thorsminde to Thyboron is 40km and consists largely of sand dunes and coastline to the west, with farmland to the east. The terrain is flat and simple, with the exception of the sand dunes, which have a maximum elevation of 35m and maximum slope of 4.8%. The elevation profile starting from Thyboron and travelling south to Thorsminde is shown in the following figure:

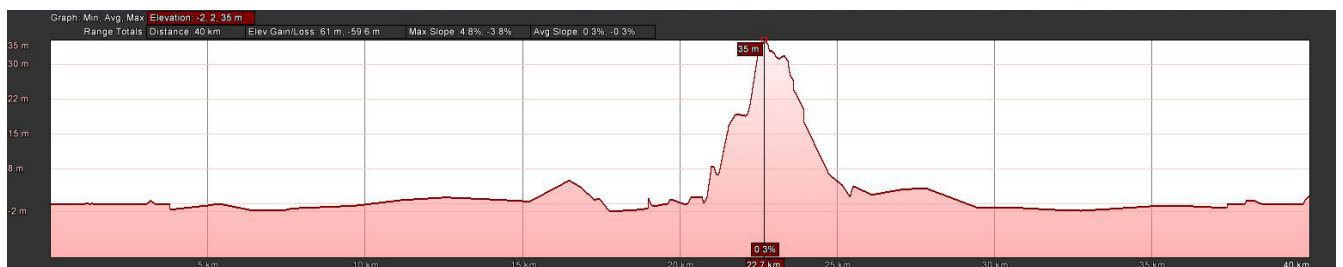


Figure 5 Elevation profile from Thyboron to Thorsminde

As the lidar needs a clear line of sight to obtain measurements, the placement must have an open view of the horizon over the North Sea. Further, the dual Doppler lidars also require a clear view inland in order to follow planned transect lines. These transect lines will record the evolution of wind fields from off to on-shore.

Viewshed diagrams (Figures 8, 12 and 17) have been rendered for the three scanning lidar positions. The regions shaded in green represent the unobstructed areas which are visible (clear line of sight) from the lidar's scanner head.

Additionally, the distances between the three lidars should be optimised such that they are equally spaced and that the dual Doppler beams will intersect at a large enough angle (typically 45 degrees).

Using Google Earth as an aid, a few potential sites were proposed:

- Thorsminde (town/harbour)
- Høvsøre sand dunes
- Coastline from Fjaltring to Ferring
- Thyboron (transition piece of the Envision wind turbine platform)

The next step was to travel by car and investigate the sites more closely. Issues including: high foot traffic (tourism at Thorsminde), sand and water intrusion (on the dunes), and movement/vibrations on the turbine platform ruled out those locations.

The coastline between Fjaltring and Ferring, however, was very promising. The shore is mainly dune-cliffs covered with grass. This ensures a clear trajectory over the sea and also lowers the risk of sand and water intrusion into the lidar and scanner head. Further, the area is isolated from nearby towns and experiences little foot and car traffic (especially during the campaign period).

## 4. The three sites selected for RUNE

The final positions for the shore based scanning lidars are given in the following table, with coordinates measured using a differential GPS system with an accuracy of within 10cm:

Site name	Address	Coordinates Lat/Long	UTM 32V
RUNE1	Kjeldbjergvej 34, 7620 Lemvig	56°28'41.9340" N, 8°07'28.5465" E	6259660.302m N, 446080.025m E, 12.358m H
RUNE2	Trans Kirke, Mollerupvej 20 7620 Lemvig	56°29'52.2744" N, 8°07'17.3133" E	6261837.494m N, 445915.641m E, 26.376m H
RUNE3	Bovbjerg Fyr, Fyrvej 27 7620 Lemvig	56°30'46.2564" N, 8°07'10.6839" E	6263507.903m N, 445823.663m E, 42.965m H

Figure 6 Table of chosen lidar positions

Ultimately, the three sites chosen for the RUNE experiment fit very well into the experimental design goals. Firstly, they are generally well spaced (2.25km RUNE1-2, 1.7km RUNE2-3) and give a wide enough angle for accuracy in dual Doppler reconstruction (41.85 degrees at 5km offshore). Further, they are in isolated areas with clear visibility over the horizon and have close-by access to electricity. The areas also pose the least possible risk to human, animal and environmental impact.

### 4.1 RUNE1

The first location (RUNE1) is the southernmost site near to Fjaltring. It sits at 12.358m ASL on a coastal cliff in front of a private home. A small surfing beach lies just south, with public toilets and a storage shed. There is a paved road leading up towards the house, which extends to a small walking path along the cliff. Electricity can be connected either to the home (with landowner's permission) or to the toilet facility. The ground is flat, grassy and level.



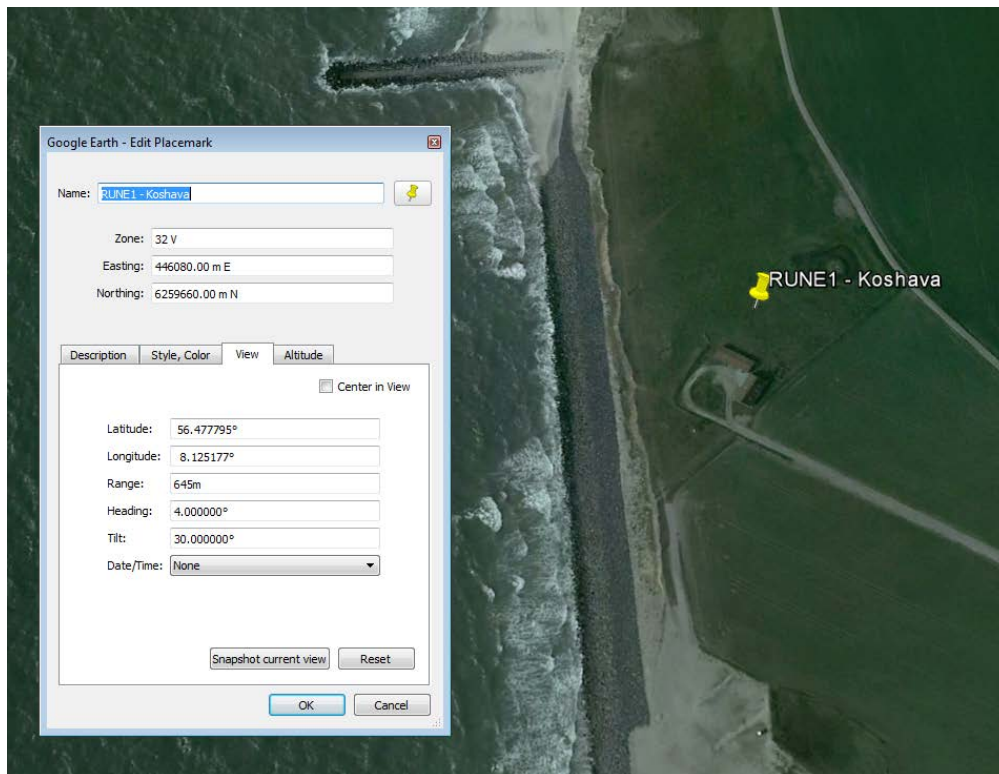


Figure 7 Details of position 1 (RUNE1) and GPS coordinates



Figure 8 Viewshed at position 1 (RUNE1)



**Figure 9** Picture taken at position 1 (RUNE1) looking north



**Figure 10** Picture taken at position 1 (RUNE1) looking south

## **4.2 RUNE2**

The second location (RUNE2) lies 2.25km north of RUNE1 within the village of Trans at a religious complex (Trans Kirke). The church was struck by lightning in 2015 and renovations were completed during the campaign. The ideal location for the lidar deployment was determined to be on top of the lavatory (a small separate building to the main church and graveyard) which has a direct view to the sea. However, as the number of profiling lidars at the RUNE2 location increased, it was decided to instead place all devices on the ground adjacent to the restroom. Electricity was supplied from the lavatory building.

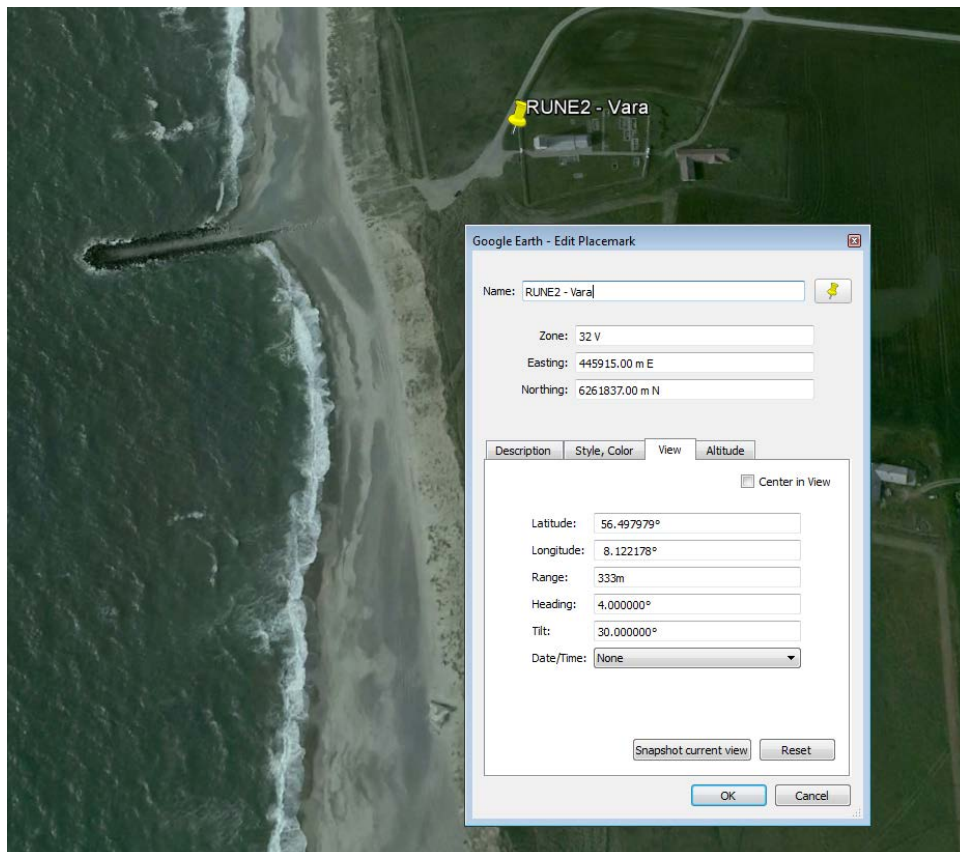


Figure 11 Details of position 2 (RUNE2) and GPS coordinates

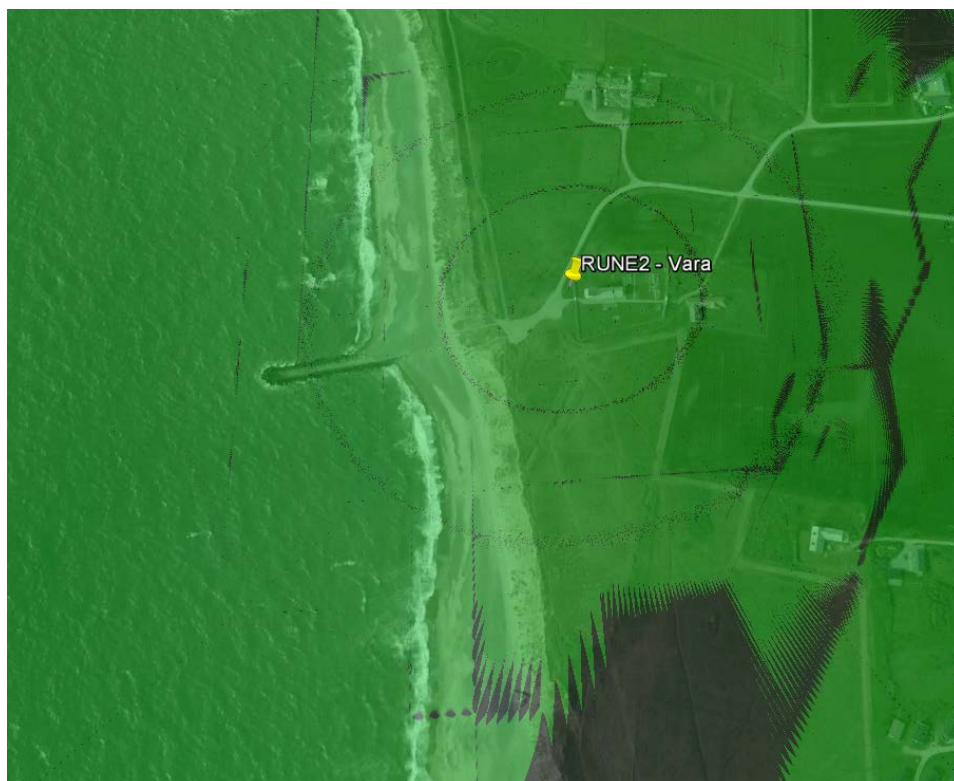


Figure 12 Viewshed at position 2 (RUNE2)





**Figure 13** Trans Kirke (RUNE2) with an arrow showing the proposed position of the WindScanner on the roof of the lavatory outside the churchyard. The final position was on the grass adjacent to the restroom.



**Figure 14** Picture taken at position 2 (RUNE2) looking north-west



**Figure 15** Picture taken at position 2 (RUNE2) looking south



### 4.3 RUNE3

The third lidar was installed 1.7km north of the RUNE2 position, near the town of Ferring at an elevation of 37m ASL. A lighthouse (Bovbjerg Fyr) and café sits 200m from the coast. 20m south of the lighthouse is an abandoned military bunker from WWII which is structurally sound but flooded with standing water on the inside. The roof is higher than human height on the lee side and is generally level. Since the area of interest lies to the south, the lighthouse is not within the scanning area. The close proximity of the lighthouse and café ensured a reliable electrical connection.

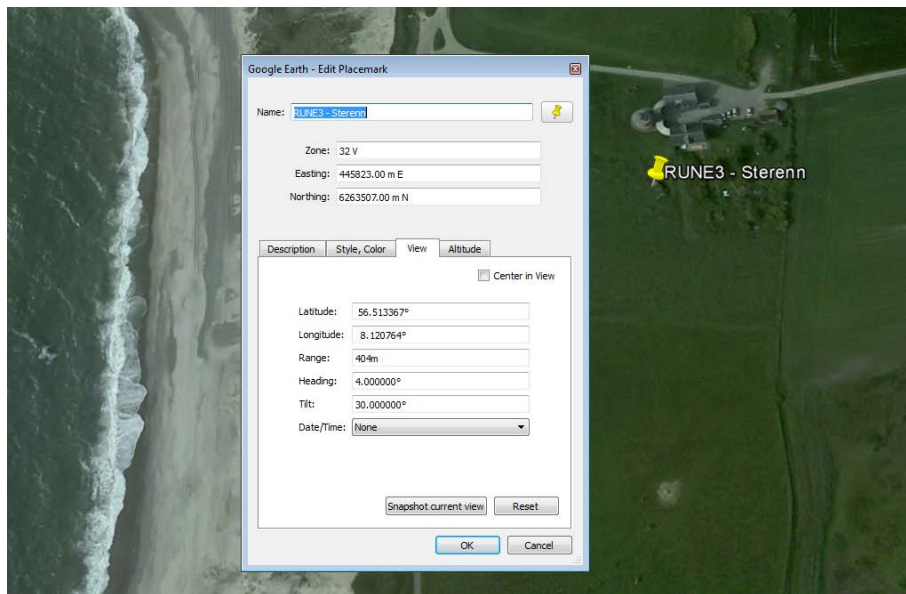


Figure 16 Details of position 3 (RUNE3) and GPS coordinates



Figure 17 Viewshed at position 3 (RUNE3)



Figure 18 Position for the installation at Bovbjerg Fyr (RUNE3) on the top of a concrete WWII bunker.



Figure 19 Picture taken at position 3 (RUNE3) looking north



**Figure 20 Picture taken at position 3 (RUNE3) looking south**

## 5. Obtaining permission from authorities and landowners

The coastline in Denmark is strictly protected by planning regulations [4]. Within a range of 100-300m, most building activity is strictly regulated in order to preserve the coastline as unchanged (natural) as possible. Deployment of equipment inside this zone ('Strandbeskyttelse', beach protection and 'Klitfredning', dune conservation) requires a dispensation from Naturstyrelsen (the Danish Nature Agency). This can be a lengthy process – up to and exceeding 6 months. In our case, likely due to the scientific, temporary nature and the relative simplicity of the application, the permission was received within 1 month. It is advisable to allow for a considerably longer processing period, particularly for commercial interests.

An alternative to seeking permission for a position inside the coastal zone is to find a position just outside the protected areas (although local council permission may still be required). For this purpose, it is first essential to understand the extent of the protected area. In Denmark, the web portal <http://arealinformation.miljoportal.dk> can be used to determine land usage rights. For example, Figure 21 shows a screenshot from this website for the position of RUNE2 (Trans Kirke). The protected area (here the 'Klitfrednings' zone) is shown with yellow shading. While a position further from the coast will usually not offer such an unimpeded view, there may be exceptions (such as small hills or terrain sloping towards the coast).

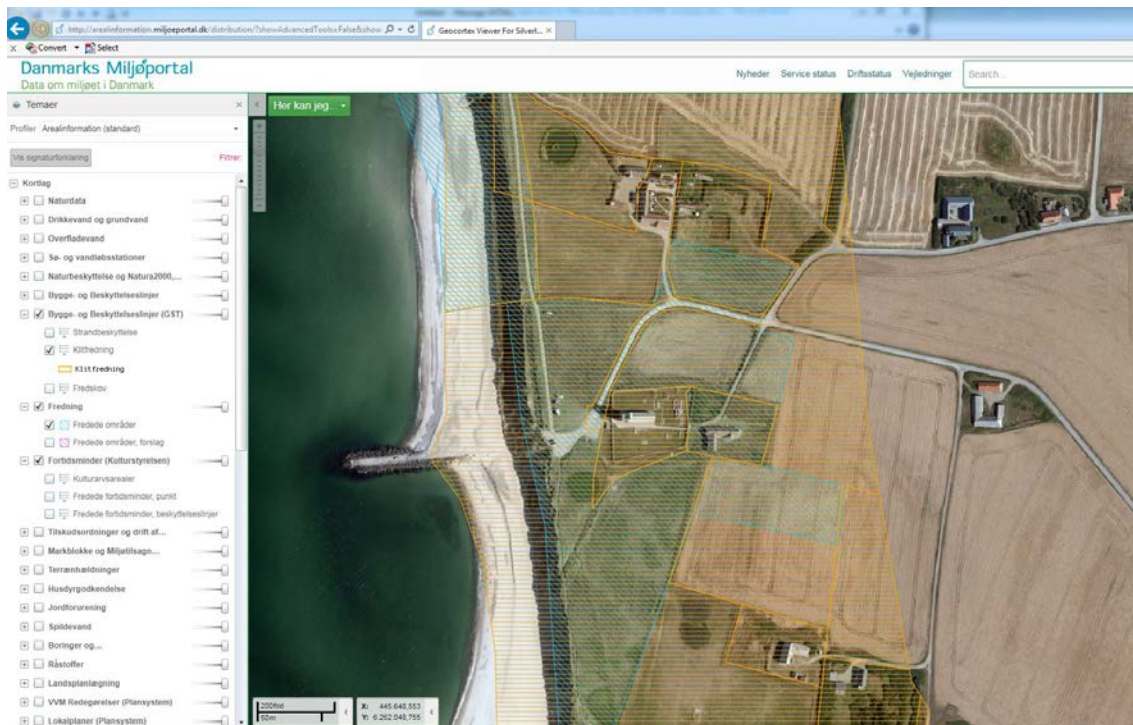


Figure 21 Screen shot from <http://arealinformation.miljoportal.dk> showing the protected coastal area around the position for RUNE2 (Trans Kirke).

## 6. The installed systems

To give an impression of the type of installations and their impact on the local surroundings, we will, throughout this section, give a mainly visual impression of the completed installations at the three RUNE sites (Figure 22 to Figure 27).

Each of the three systems were placed on grassy soil. This is not optimal, since the grass and soil will sink somewhat due to the weight of the scanners. Further, rainwater has the ability to influence the behaviour of the soil settling. We have chosen to use a plastic plate to spread the load (see Figure 22). The scanner itself is placed on a reinforced wooden pallet. Blocks, planks, wedges and stones are used in conjunction with the internal digital inclinometer for levelling (see Figure 27). A more stable and robust mounting could be achieved by driving a number of wooden stakes into the ground and building the scanner platform on this.

Electricity is supplied from a temporary panel (as typically used on a building site) installed by a local electrician. The panels have been placed as unobtrusively as possible (see Figure 25). An electricity meter is provided in each panel so as not to financially encumber the local land owners. Each system uses about 30kWh per day. In order to provide a well-functioning ground connection, we have driven a copper earthing-stake into the ground at each of the installations. This can be seen in Figure 24, just to the left of the power supply panels. Network communication has been achieved using a 4G wireless link and a Cisco 'Meraki' VPN. The network equipment is placed in a plastic box (with a weight on the lid), clearly visible in Figure 24.





**Figure 22** RUNE1 installation



**Figure 23** RUNE2 installation at Trans Kirke





**Figure 24** Details of the RUNE2 installation showing the power supplies, GPS antenna, earthing pole and communications box.



**Figure 25** The mains electricity supply panel positioned unobtrusively at the RUNE2 installation.





**Figure 26** The RUNE3 installation at Bovbjerg Fyr.



**Figure 27** Photo of the RUNE3 installation.

## 7. Conclusion

The concept of scanning lidars placed at coastal sites in order to measure the near-coastal (offshore) wind resource has been presented. Desirable features of sites for deploying such scanning lidars have been examined. It has been seen that the most favourable sites are cliff tops, away from sand dunes, and with reasonably easy access to mains electrical power. Generally, such sites in Denmark will be within the rather strictly controlled coastal planning zone and it is very likely that permission from the national environmental agency (Naturstyrelsen) will be required. Sufficient time should be allowed for this process.

The report concludes with a mainly pictorial description of the 3 RUNE coastal installations together with their exact positions and some indications of possible technical improvements for future deployments.



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